Rod-Shaped Semiconductor Nanocrystals Synthesized

Novel Properties, Applications Seen

A research team led by Paul Alivisatos at LBNL has reported in *Nature*, its success in synthesizing the first semiconductor nanocrystals with controlled, non-spherical shapes. This work represents a significant step towards improving the light emission and other properties of these nanoscale materials.

Semiconductor nanocrystals are of intense scientific and technological interest because their fundamental properties, for example their bandgap and light emission wavelengths, are functions of their size. As a result, a device composed of semiconductor nanocrystals of the same material, but of different sizes, could be made to emit several wavelengths of light in response to excitation by a single wavelength. To date, these semiconductor nanocrystals have all been approximately spherical in shape ("quantum dots"), with their electrons confined in all three directions. A variety of interesting effects have been predicted for nanoscale systems in which the electrons are confined in only two directions, as in a prolate "quantum rod" with a sufficiently large aspect ratio to provide quantum confinement along only its two short axes. However, until now, no synthetic methods existed to produce these semiconductor quantum rods with sufficient size and shape control.

The Berkeley team has achieved this synthesis by modifying the growth techniques they developed to provide shape and size control for spherical CdSe nanocrystals. (MSD Highlight 94-1) In their usual procedure, Cd and Se precursors in solution are injected into hot solvent (TOPO: trioctyl phosphine oxide). The conditions are chosen such that the Cd and Se nucleate CdSe nanocrystals, but the nanocrystals are allowed to grow for only a short period of time, producing quantum dots with a narrow size distribution. CdSe is, however, intrinsically anisotropic, with a unique "c-axis," and the team discovered that when the CdSe growth rate is fast, it is fastest along this axis. In addition, the team found that by adjusting the nature and concentrations of the "surfactants" that are used to terminate the nanocrystals growth, they could achieve additional control of the growth kinetics. Using these techniques, the team was able to produce CdSe quantum "rods" elongated along their c-axes with aspect ratios as large as 10.

The team then compared quantum dots (nominally 3.5 nm in diameter) with their new quantum rods (long axis / short axis = 6.6 nm / 3.6 nm). In the latter system quantum confinement effects are expected only along the short axes of the rod. Quantum dots exhibit a significant overlap between their visible light absorption and emission (photoluminescence) curves (see figure); this leads to a technical problem involving re-absorption of photons when they are used in light emitting diodes. However, the team discovered that there is a 25% decrease in this effect in the case of the quantum rods, indicating that these materials might be very useful in light emission applications. In another experiment the team embedded the rods into a solid polymer and stretched it in one dimension, obtaining partial alignment of the rods along the stretching direction (see figure). Light emission was found to be preferentially polarized parallel to that direction. No such preferential polarization was found in quantum dots under the same conditions. This characteristic could make the rods useful in biological tagging experiments where the orientation of the cellular structures needs to be determined. (MSD Highlight 99-7)

Paul Alivisatos (510.642-7371), Materials Sciences Division (510.486-4755), E. O. Lawrence Berkeley National Laboratory.

Xiaogang Peng, Liberato Manna, Weidong Yang, Juanita Wickham, Erik Scher, Andreas Kadavanich, and A. P. Alivisatos, "Shape control of CdSe nanocrystals," *Nature* **404**, 59 (2000).